WHISTLE PRODUCTION RATES IN A GROUP OF BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS)* AMONG CHANGES IN GROUP COMPOSITION IN SARDINIA, ITALY

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Abstract

This study focused on the whistle characteristics and production rates of a resident group of bottlenose dolphins (*Tursiops truncatus*) in Golfo Aranci, Sardinia, Italy. All recordings and observations were conducted at the local fish farm located 200 meters from the shore in Golfo Aranci. Three hundred and eighty minutes of underwater sounds were recorded using a single hydrophone system during the months of June and July 2007. Whistles were separated both according to group size, from one to seven dolphins, and group composition for statistical analysis. The acoustic characteristics of 176 whistles were classified based on eight parameters and compared with data of previous studies. A significant positive correlation ($r = 0.457$, $p \leq 0.001$) was observed between whistle rates (whistles per minute) and group size observed at the time of measurement, supporting our hypothesis that whistle rates increase in groups of larger numbers as compared to groups of smaller numbers. Additionally, whistle production rates of adults in the presence of an immature calf showed a significant difference to those of any other group ($p \leq 0.05$) and had a higher whistle production rate (median = 0.5 whistles/minute/individual), while all other groups were not significantly different in the production of whistles ($p \geq 0.05$, median = 0 whistles/minute/individual). Whistles recorded at Golfo Aranci were of longer duration and higher maximum and minimum frequencies than that reported in previous studies. The results suggest that the whistle rate of bottlenose dolphins is affected by both group size and composition, with higher whistle rates in larger groups and in the presence of immature dolphins.

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Preface

The vocal repertoire of bottlenose dolphins (*Tursiops truncatus*) and other cetaceans has fascinated the scientific community for many years. Because bottlenose dolphins live in an aquatic environment, they rely on sound production as their primary form of communication. Of dolphin vocalizations—echolocation, burst pulsed sounds, and whistles—whistles have been the most studied. The importance of dolphin whistles has been demonstrated through their use in group cohesion, courtship, and social episodes in general. While these aspects of whistle production have been widely studied in captivity, the whistle production rates and whistle contour of dolphin groups in the wild have received limited study.

The purpose of this study was to compare the whistle production rates of known bottlenose dolphins with respect to changes in group composition and group size in a wild population. The study consisted of three aims. The first objective was to study the effect of group size on whistle production rates. Underwater recordings were separated into one minute increments and used to compare the whistles per minute in each sample to the number of dolphins in the group. The second objective was to study the effect of group composition on whistle production rates, particularly the effect of the presence of a newborn calf. Whistles rates were calculated on a whistle/minute/individual basis and separated into five group composition categories for comparison. Lastly, recorded whistles were characterized on the basis of eight parameters and compared to those of previous studies.

Review of Literature

Bottlenose dolphins (*Tursiops truncatus*) are highly social animals with fine tuned abilities in sound reception and production. As such their vocal behavior has captured the interest of the scientific community for the past four decades. Many aspects of delphinid vocalizations, including signature whistles, echolocation, and burst pulsed sounds, have been studied fervently, with the majority of studies being conducted on captive bottlenose dolphins (Caldwell and Caldwell, 1965; Popper, 1980; Tyack, 1986; Harley et al., 1996; Janik and Slater, 1998). At present, there exists very little information in the scientific literature on the vocal production and behavior of free-ranging and wild bottlenose dolphins. This information deficiency is due to the inherent difficulties encountered when studying animals in their natural environment, such as lack of access to animals and poor underwater viewing conditions. As such, we still know very little about the use of whistles by wild dolphins and the rate at which they produce them.

Dolphin Societies

Bottlenose dolphins are highly social animals that live a complex fission-fusion society, a society in which members associate in smaller groups within the larger community. These smaller groups tend to change rapidly in composition, with the exception of long term relationships such as between mothers and calves. Community members are rarely seen all together with distance among different members extending as far as several kilometers. A dolphin group can consist of an adult male and female, two sub adult males, two subadult males with two females, or other possible combinations.

Populations are found primarily in tropical and temperate waters with herd sizes varying with openness of the surrounding environment (Bazúa-Durán, 2004). Inshore populations are often resident to a given area, similar to the resident dolphin community in this study, while offshore populations may range over much larger areas. Community size tends to consist of less than 50 individuals when close to shore and larger numbers when offshore, with reports of herds as large as several thousands (Wells et al., 1980). Sizing of groups within the community is also affected by behavior such as increasing during feeding events presumably to enhance feeding strategy (Acevedo-Gutiérrez and Stienessen, 2004).

Within dolphin societies it is common for individual dolphins to form long term bonds with other members. For example, mother and calf associations may be strong and last for several years. Reproductively active females gestate for twelve months before bearing a single calf every two or three years. Calves stay with their mothers for an average of three to six years and form a strong bond with her (Smolker et al., 1993). Calves are weaned when they are three to five years old, but do not reach maturity until they are eight or twelve (Tyack and Clark, 2000).

Before reaching maturity it is extremely common for males to form bonds with one other male (dyad) or two other males (triad) in associations called ‘alliances’. Alliances can remain stable for years and can form temporary, secondary alliances with other stable alliances (Connor et al., 2001). An alliance is beneficial to its members as it reduces the amount of competition for resources and females. Female dolphins, on the other hand, do not form pair-bonds. Instead, females affiliate with a small group of females and this group may overlap with several other female groups (Smolker et al., 1993). Such common associations among both male and female dolphins suggests that individual relationships are an important aspect of dolphin communities.

In complex societies, such as fission-fusion societies, a mechanism for maintaining group cohesion is advantageous. It has been widely accepted that dolphins are capable of maintaining group coordination and synchrony with other members, and they maintain such cohesion through vocal communication (Lammers and Au, 2003).

Bioacoustics

The physical characteristics of water and air are significantly different. One such difference is the lack of light at depth. With increasing depth, scattering and absorption reduce the light intensity exponentially. Additionally, water is not always clear and can be clouded by algae, mud, and sediment. In such an environment, it is unlikely that vision would serve as the primary sense of marine mammals as it is for terrestrial mammals. Water does, however, serve as a better medium for sound travel due to its density. Sound travels approximately 4.5 times faster in water than it does in air (Morisaka et al., 2005). Given the nature of the marine environment, marine mammals, including bottlenose dolphins, have adapted to use hearing as their primary sense (Ridgway, 1990).

Dolphins are capable of producing a wide range of vocalizations and can hear high frequency sounds well beyond 100 kHz (Au, 2000). Although their sound repertoires have been described to include whistles, buzzes, quacks, pops, yelps, and clicks (Jacobs et al., 1993), bottlenose dolphin vocalizations can be divided into three categories: broad-band echolocation clicks, broad-band burst pulsed sounds, and frequency-modulated narrow-band whistles (Caldwell et al., 1990). These vocalizations are thought to be associated with certain behavioral categories. Whistles are considered useful for social interactions and group coordination, while burst pulsed sounds and clicks are mainly used for navigation and hunting (Kellogg, 1961; as sited by Jacobs et al., 1993). However, all of these categories seem to play a role in social interaction as well (Herman and Tavolga, 1980).

Burst Pulsed Sounds

Burst pulsed sounds are a major category of sound emission for bottlenose dolphins. Most of the research on social sounds to date has been done on whistles as whistles are mostly in the audible range and therefore more easily recorded. Burst pulsed sounds are characterized by a high repetition rate greater than 300 pulses per second or by low interpulse intervals less than three milliseconds long (Au, 2000). These sounds have a frequency component that extends beyond 100 kHz (Au et al., 1999; as cited by Au, 2000). Click structures can vary in amplitude and rate resulting in variations in sound which are perceived by the human ear as squawks, squeals, cracks, snaps, bleats, barks, groans, or moans (Popper, 1980).

Like whistles, burst pulse sounds are considered social sounds and occur commonly in social or emotional contexts. These sounds have been observed in agonistic encounters as well as in play. It is even common for whistles to be found overlapping, at the beginning of, or at the end of burst pulsed sounds (Au, 2000).

Echolocation

Dolphins are skilled at acoustic processing and frequently make use of this ability in an environment where vision may be impaired (for example muddy or cloudy water). Although dolphins have very good vision compared to other mammals, echolocation provides more detailed information about their environment than from vision or any other sensory system. In experiments done by Harley et al. (1996), dolphins presented with an object and rewarded to select an identical object performed better when objects were presented only for echolocation than when they were presented only for vision.

Echolocation involves the production of short broadband high-intensity clicks and using the returning echoes to determine the characteristics of the surrounding environment (Delong et al., 2007). These pulses are emitted from the dolphin's melon, or forehead, in a focused beam and returning echoes are received through the lower jaw and pass to the inner ear. Echolocation sounds can vary in click length and frequency. Dolphins are capable of making fine discrimination over underwater distances up to at least 100 m (Au, 1980). The information that a dolphin can perceive about an object from the echoes include determination of size, shape, distance, direction, speed, and internal structure of an object.

Whistles

Whistles are described as frequency modulated sounds with a fundamental frequency ranging from 5 to 14 kHz and lasting anywhere between 0.1 to 4 seconds (dos Santos et al., 2005). Dolphins can produce many different types of whistles which can differ in frequency, duration, and amplitude. Whistles serve a variety of social purposes including communicating social information, coordinating movements during hunting (Norris and Dohl, 1980), and identifying individuals through a type of whistle called a "signature whistle" (Caldwell et al., 1990).

Bottlenose dolphins' ability to produce individually unique stereotyped vocalizations termed "signature whistles" was first demonstrated by Caldwell and Caldwell (1965). They found that each individual dolphin's signature whistle is distinctively unique in contour, the rising and falling pattern of frequency modulation or structure of the whiste, to that of any other dolphin, lending it to many functions including individual identification (Cook et al., 2004). Experiments done by Sayigh et al. (1999) demonstrated that captured dolphins can differentiate between signature whistle recordings of familiar individuals. Additionally, signature whistles function in group cohesion; Janik and Slater (1998) demonstrated that temporarily isolated bottlenose dolphins produced signature whistles, which provided a means of locating and maintaining contact with other dolphins.

Dolphins are not born with a signature whistle, but develop their whistles around the age of four to six months (Sayigh et al., 1990). Bottlenose dolphins are one of the few mammalian species that have evolved the ability to learn new sounds, and calves tend to model their signature whistles on the whistles they hear from other familiar dolphins (Fripp et al., 2005). According to Sayigh et al. (1990), spectrograms of young female and male calves show female calves produced whistles that were quite distinct from their mothers, while male calves produced whistles similar to their mothers. As females tend to associate with their mother's group after reaching maturity, having a distinct whistle from their mother may avoid confusion in the group. Male calves, on the other hand, tend to not associate with their mothers once they reach maturity. The whistles of males also are less stable than those of females. Adult males have been shown to modify their whistles to be similar to other members of their alliances with whom they share a strong social bond (Smolker and Pepper, 1999). Calves also model their whistles after individuals with whom they have spent only limited time, to aid in making their signature whistles distinguishable from those they normally associate (Fripp et al., 2005).

Signature whistles have been thoroughly studied by many researchers who have varying opinions on their importance. Signature whistles have been reported the most frequently emitted whistle type in both captive (Caldwell et al., 1990) and temporarily captured free-ranging individuals, accounting for approximately 70 to 80 percent of all whistles produced (Sayigh et al., 1990). Other studies have found a lower percentage. Tyack (1986) found the percentage of signature whistles from two bottlenose dolphins were close to 67 percent and 48 percent of total whistles produced, respectively. However, some researchers remain skeptical about the importance of signature whistles or even their existence. McCowan and Reiss (2001) found similar and different social groups produced a predominant whistle type that was shared among the group in social and isolated contexts. These researchers suggested signature whistles do not exist at all, but rather dolphins produce a shared whistle of their group members.

<u>Interaction with fisheries</u>

Over the past decade, aquaculture, the farming of fish and shellfish, has expanded in the Mediterranean Sea and other parts of the world (Díaz López and Bernal Shirai, 2007).

Costal marine fish farms attract many marine predators, including bottlenose dolphins, with their abundant food source. After workers feed the fish, some of the food falls through the nets and into the area surrounding the nets. This excess food attracts many local species of fish to fish farm areas, and this dense population of fish attracts predators such as dolphins. Association of bottlenose dolphins with fish farms is thought to be advantageous to the animal by decreasing the energy expended during feeding and increasing feeding rate (Díaz López, 2005). It is also speculated that lactating females will forage around fish farms to meet the increased energy demand of lactation.

Since a fish farm was built in Golfo Aranci in 1992, there has been a regular appearance of a local residency of dolphins. These dolphins use the Golfo Aranci area as a feeding ground year round, with the majority of their feeding behavior occurring at the local fish farm (Figure 1 and 2). The regular appearance of this group at the fish farm enables researchers to study a common group of dolphins in their natural setting.

Bottlenose Dolphin Research Institute (BDRI)

The Bottlenose Dolphin Research Institute (BDRI) is a small privately owned research center based in Golfo Aranci, Sardinia, Italy. This institute strides to contribute to the understanding and conservation of bottlenose dolphins through different non-invasive research techniques. Prior to 1999, very little was known about the bottlenose dolphin populations that inhabit the waters around Sardinia Island. In 1999 an Italian nonprofit organization called Accademia del Leviatano started the “Dolphin Project” in collaboration with cetacean researcher Bruno Díaz López. This project grew to include studies of a wider range of issues eventually becoming established as the Bottlenose

Figure 1. Dolphins feeding at the fish farm.

Figure 2. Female bottlenose dolphin feeding at the fish farm.

Dolphin Research Institute in 2004. Over the years this institute has participated in long-term population monitoring, study of foraging and acoustic behavior, and potential effects of human aquaculture on Mediterranean bottlenose dolphin populations.

Present Study

In this study, whistles of a known group of bottlenose dolphins were recorded and analyzed in order to determine how whistle production rates vary during changes in group composition during feeding episodes. All observations and recordings were collected at a local floating marine fin fish farm in the Golfo Aranci, with factors such as location and equipment used held constant. Previous studies have shown the existence of a common group of bottlenose dolphins that routinely utilize the fish farm for feeding year round (Díaz López and Bernal Shirai, 2007). As a result, this field study provides a unique opportunity for regular access and close monitoring of a known group of free-ranging bottlenose dolphins.

It was hypothesized that the rate of whistles will increase in groups of larger numbers as compared to groups of smaller numbers and with the presence of a mother and calf pair. It is suspected that during these encounters there may be an increase in the quantity of whistles from both the mother/calf pair and from joining members, influencing the whistle production rate of the group as a whole. Although the data collected is only from one study site, it is possible to extrapolate these results to other areas where bottlenose dolphins regularly interact with fin fish farms. Understanding this potential influence of group size and composition on whistle production rates may prove important for further studies on the behavior of dolphin groups.

Materials and Methods

<u>Study Area</u>

This study was carried out in the Golfo Aranci on the north-eastern coast of Sardinia, Italy (Figure 3). All data were collected at the local fish farm which is located 200 meters from the shore and covers 2.4 hectares (40º 59' N, 9º 37' E). This sea-cage fish farm, managed by Compagnie Ittiche Riunite (CIR), was set up in 1992 and consists of 21 floating cages. The cages are grouped into three rows of seven cages in each row. Each cage is 22 meters in diameter and 15 meters deep. The cages are made of nylon mesh netting and contain 800 to 900 tons of ichthyic biomass, sea bass (*Dicentrarchus labrax*), guilthead sea bream (*Sparus auratus*), and corb (*Sciaena umbra*) (Díaz López et al., 2005). Average water depth of the fish farm is 22 meters with a maximum of 26 meters. The water temperature averaged 26 degrees Celsius during the months of June and July. Water clarity was measured by a Secchi disk and averaged 22 meters for both June and July. Sea floor in the study area is mainly characterized by mud with scatterings of rock and sand.

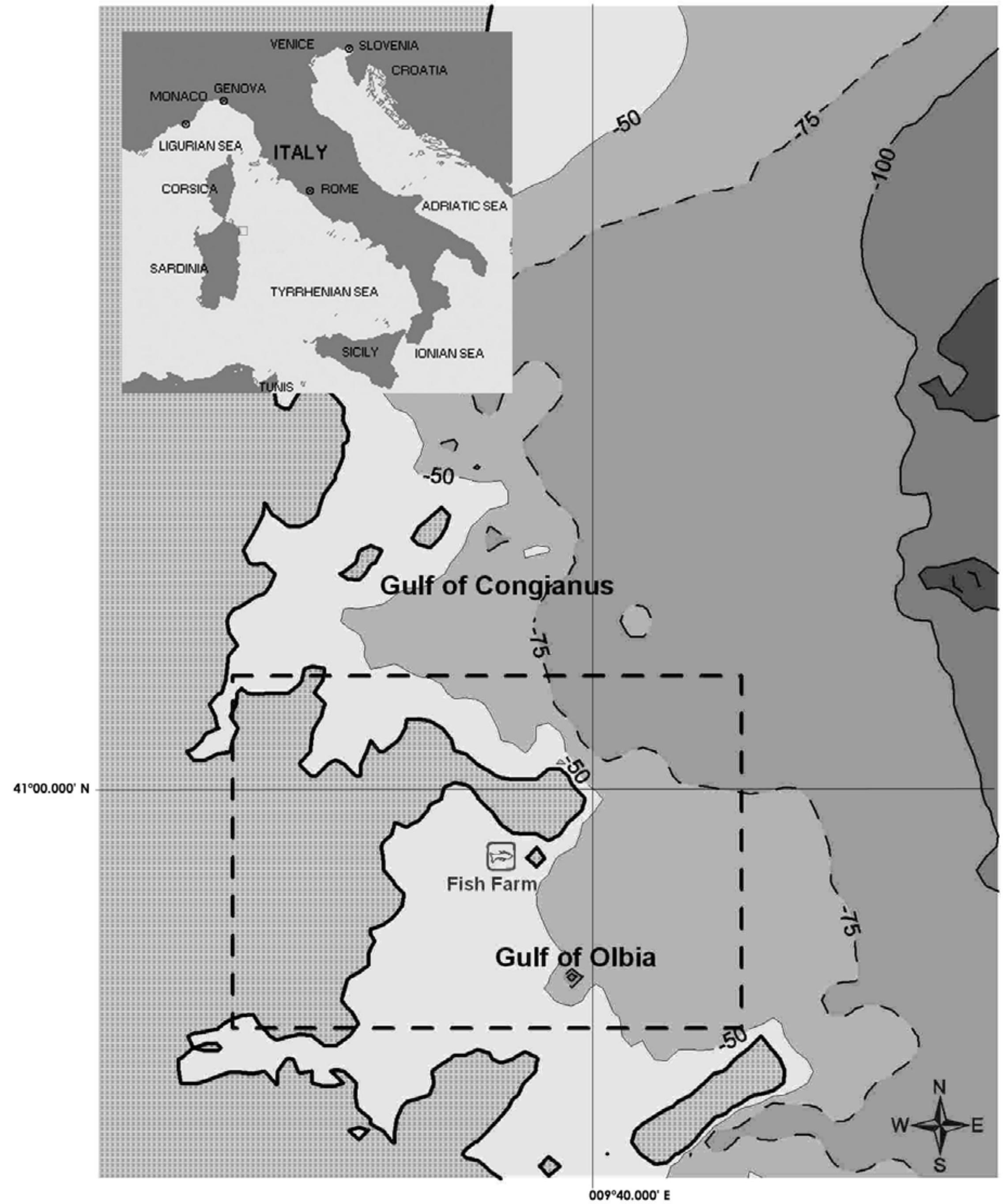

Figure 3. Map of northeastern Sardinia Island, showing location of the fish farm area (Díaz López et al., 2005).

Field Data Collection

Vocalizations of a known bottlenose dolphins were recorded during the months of June and July in Golfo Aranci, Sardinia, Italy. Sightings and recordings were made from a 30m long Starcraft boat with an outboard Yamaha 25hp motor stationed at the local fish farm in Golfo Aranci (40º 59' N, 9º 37' E). Spotting and observations were conducted during different times of the day including morning, afternoon, and evening with the naked eye. Local time was converted to solar time to account for shift due to daylight saving time.

During field research efforts, surveys were conducted every 20 minutes to record environmental measurements: position (measured by GPS), swell direction, wind speed and direction, water clarity (using a Secchi disk), water temperature, presence and types of boats, sea state, fish presence (GARMIN 120 Fish finder), dolphin presence, and presence of other local species in the area. A sighting began with the first observation of a dolphin group and continued until either the group composition changed or they were considered lost after 15 minutes without a sighting. A dolphin 'group' was considered one or more dolphins observed in the same area and participating in the same behavior. Group size, composition, number of immatures and adults, behavior, and individual identification were recorded during each sighting using methods described by Würsig and Jefferson (1990). Individuals were identified by basis of their dorsal fins through the visible shapes and scars that distinguish each dolphin from another. A Nikon D70 camera was used for photo documentation and confirmation of estimated group size and composition. Sightings were considered satisfactory if visibility was not impaired by rain or fog and the sea state fell at or below a three on the Beaufort and Douglas scale.

Underwater sounds were recorded using a single Aquarian Hydrophone System with frequency response of 20 Hz to 100 kHz. For each recording, the hydrophone was placed approximately 9 meters below the water and connected to a portable Professional 2-Channel Mobile Digital Recorder (MicroTrack 24/96). The recordings were mono with a resolution of 16 bit and a sample rate of 96 kHz. The engines were turned off to avoid noise pollution during recordings. Group size, individual identification, behavior, and duration were documented during each recording. All events were recorded in real time. Underwater vocalizations were only recorded during feeding episodes in the fish farm area.

Data Analysis

Digital recordings were transferred to a computer and converted from MP3 to wave using a Power MP3 MWA Converter Version 1.15 (Copyright 2003/Coolsoft). All sounds were then analyzed using the spectrogram program S.1.6 (Copyright 1994 to 1999) designed by R.S. Horne. This software provides graphic representation of underwater sound signals, an example of which is shown in Figure 4.

Recordings were cut into one minute samples and analyzed by reading structural parameters on the spectrogram and listening to the sounds simultaneously. Only samples with qualified sounds were cut and stored for statistical analysis (sounds with noise pollution higher than four kHz were discarded).

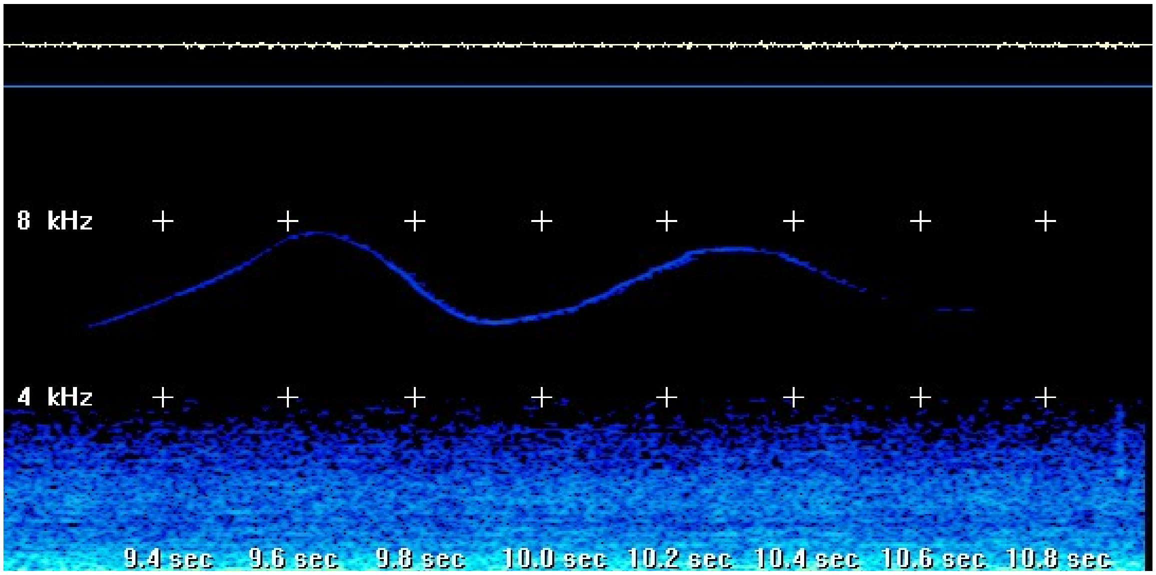

Figure 4. Spectrogram representation (S. 1.6, Copyright 1994 to 1999, by R.S Horne).

Whistles were identified and separated manually by two persons using a spectrogram and analyzed for whistle type and rate. Manual separations of whistles using spectrograms have been shown to be as effective as computerized sorting and sometimes even more so (Janik, 1999). Whistle rates were calculated manually on a whistle/minute and whistle/minute/individual basis and separated into group size and group composition, respectively. Group composition was categorized by solitary, pairs, groups of adults (three or more adults), groups of adults and immatures, and female and immature.

Whistles of acceptable signal-to-noise ratio were examined and described using the Sound Ruler program Version 0.9.4.1. Whistles were classified based on the following eight parameters: initial frequency, final frequency, quarter frequency, half frequency, second quarter frequency, minimum frequency, maximum frequency, and duration. An example of some of these parameters in a recorded whistle is shown in Figure 5. To describe the whistles, mean values, standard deviation, minimum, and maximum for all parameters were calculated. Of the 382 whistles that were collected in 13 recorded sightings, only 176 whistles were analyzed. We were unable to analyze more whistles due to the poor signal-to-noise ratio or poor visual quality. To describe the whistles, the mean values and standard deviation of all whistle parameters were calculated for all feeding episodes. These whistle characteristics were then compared with published data available from other bottlenose dolphin populations.

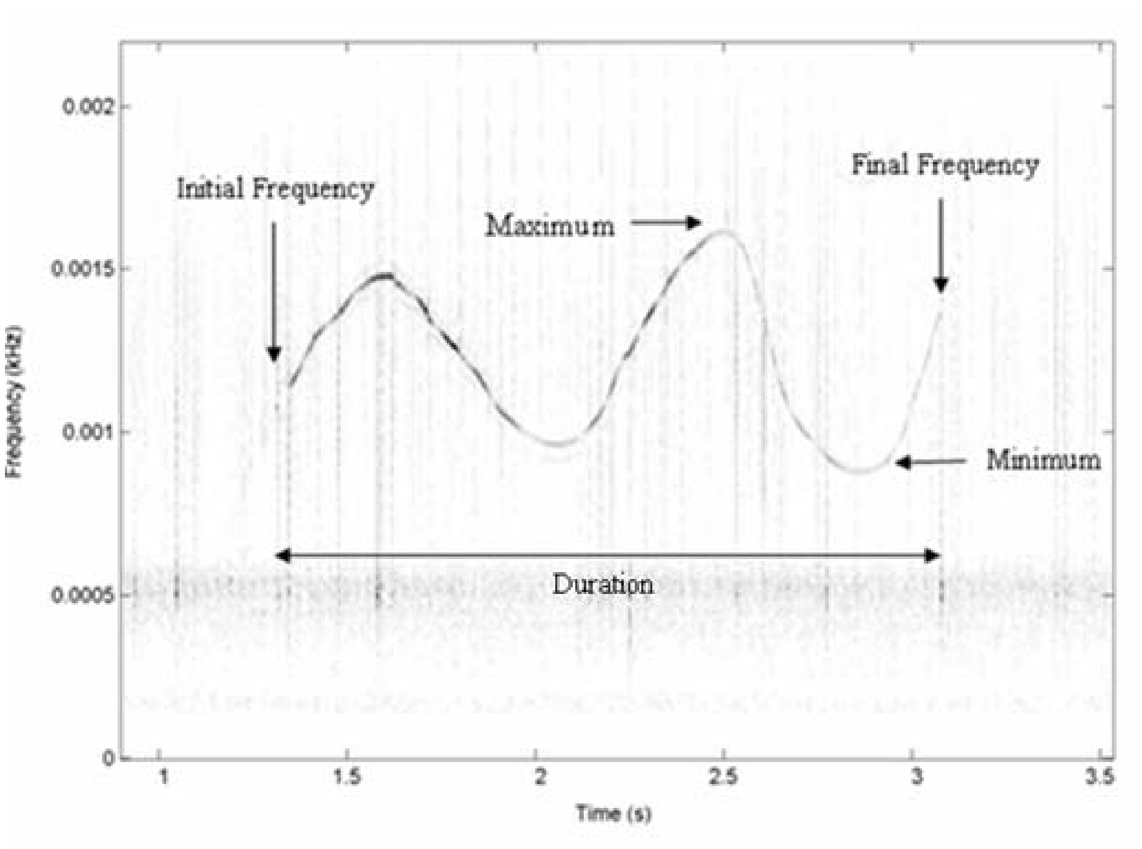

Figure 5. Visualization of five of the eight parameters measured from each recorded whistle contour.

All statistical tests were performed with the statistical package Palaeontological Statisitics, PAST, Version 1.35 (Hammer, Harper and Ryan, 2001). Non-parametric statistical procedures were adopted for whistle production rate analysis. For statistical analysis, 20 whistle rates per individual were selected at random from each group composition category to unify the samples and avoid possible bias. The Kruskal-Wallis test was then employed to analyze the differences in whistle production rates among the varying group compositions. The Spearman rank correlation coefficient was calculated to compare the whistles per minute among groups of different size.

Results

During the months of June and July boat-based underwater acoustic recordings were conducted accumulating 2054 minutes of bottlenose dolphin observation. A daily bottlenose dolphin encounter ratio (DER), or number of dolphin sightings per searching effort, was determined as 0.451 for this study (DER = minutes of dolphin observation / minutes of total observation). A total of 13 sightings were conducted resulting in 380 minutes of recorded underwater sounds (Table 1). All dolphin sounds recorded were from a known group of resident dolphins that are regularly present at Golfo Aranci due to the presence of a local fish farm. The 380 minutes of recorded sound provided a total of 382 whistles for analysis and whistle production rate calculations.

Table 1. Days and recorded time of underwater sounds recorded between June and July, 2007.

Date of Sighting	Total Sighting Duration	Total Recorded Minutes
June 6	50	53.8643
June 8	24	2.4632
June 11	171	62.3643
June 13	246	2.1959
June 20	80	52.2634
June 20	98	23.9289
June 21	70	9.9938
June 21	72	27.0248
June 21	29	9.9908
June 22	84	23.4614
June 30	140	50.1148
June 30	123	47.8361
July 2	36	13.7059

Whistle Production Rates

A total of 380 recorded underwater minutes were analyzed for whistle abundance and characteristics. Data was found to follow a non-parametric distribution through the Shapiro-Wilk test ($p \leq 0.05$) and therefore non-parametric statistical procedures were employed. Additionally, whistle production rates on given sighting dates and duration of the recorded samples were compared with Spearman correlation and revealed these two variables to be not significantly correlated ($r = 0.237$, $p \geq 0.05$) and were not influencing each other.

Hypothesis 1: The rate of whistles will increase in groups of larger numbers as compared to groups of smaller numbers.

Distribution of dolphin group size, or the number of dolphins present, for the 380 recorded minutes is shown in Figure 6. The two and three dolphin group sizes represent the majority of recorded underwater minutes, while the single and four dolphins category represents the least amount of recorded minutes. Calculated whistles per minute and the number of dolphins present during feeding episodes were compared using the Spearman correlation test with the expectation of a significant positive relationship. As expected, a highly significant positive relationship was observed ($r = 0.457$, $p \leq 0.001$), supporting our hypothesis that whistle rates increase in groups of larger numbers as compared to groups of smaller numbers. This positive correlation can be seen through the mean and standard deviation values of whistles per minute for all groups which are shown in Figure 7.

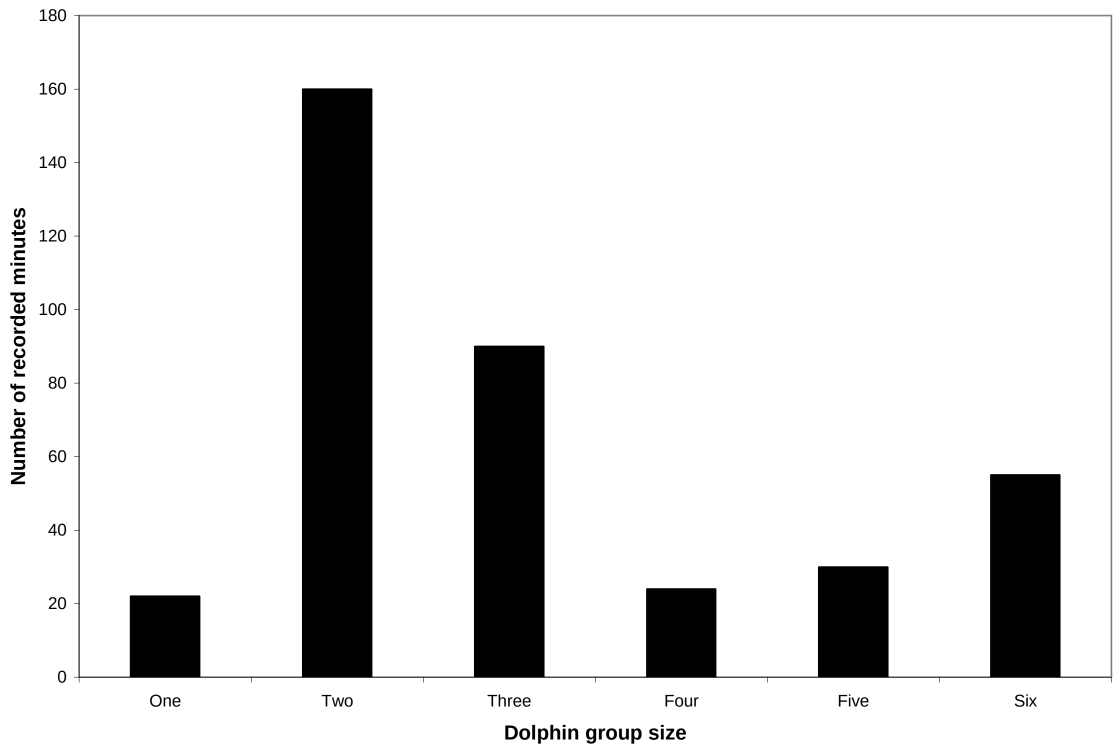

Figure 6. Distribution of dolphin group size for 380 recorded underwater minutes.

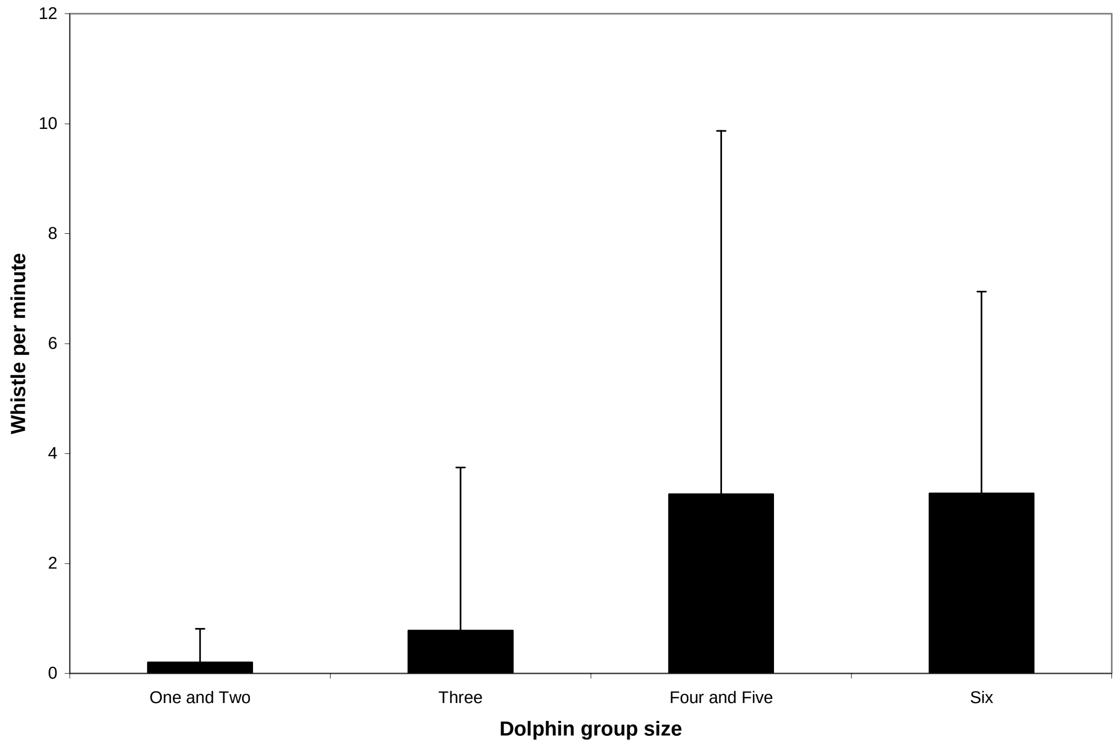

Figure 7. Mean and standard deviation values of whistles per minute for all dolphin group sizes. Due to the unequal distribution of recorded minutes among group sizes, group sizes with less than 30 minute samples were grouped with the next group size up.

Hypothesis 2: The rate of whistles will increase with the presence of a mother and calf pair.

Because the number of dolphins was previously shown to influence whistle rates, whistle production rates were calculated on a whistles per minute per individual basis and separated into five composition categories: solitary, pair, adult group (three or more adults), adult group and immature, and female and immature. Dolphin group composition distribution for the 380 recorded minutes is shown in Figure 8. The distribution of recorded minutes was not equal among the five categories with the majority of the recorded minutes falling into the Adult Group and Pairs categories and the least amount of recorded minutes falling into the Solitary and Female and Immature categories. Due to the unequal distribution of recorded minutes among the five categories, twenty whistle per minute per animal samples were selected at random from each composition category to unify samples for statistical analysis.

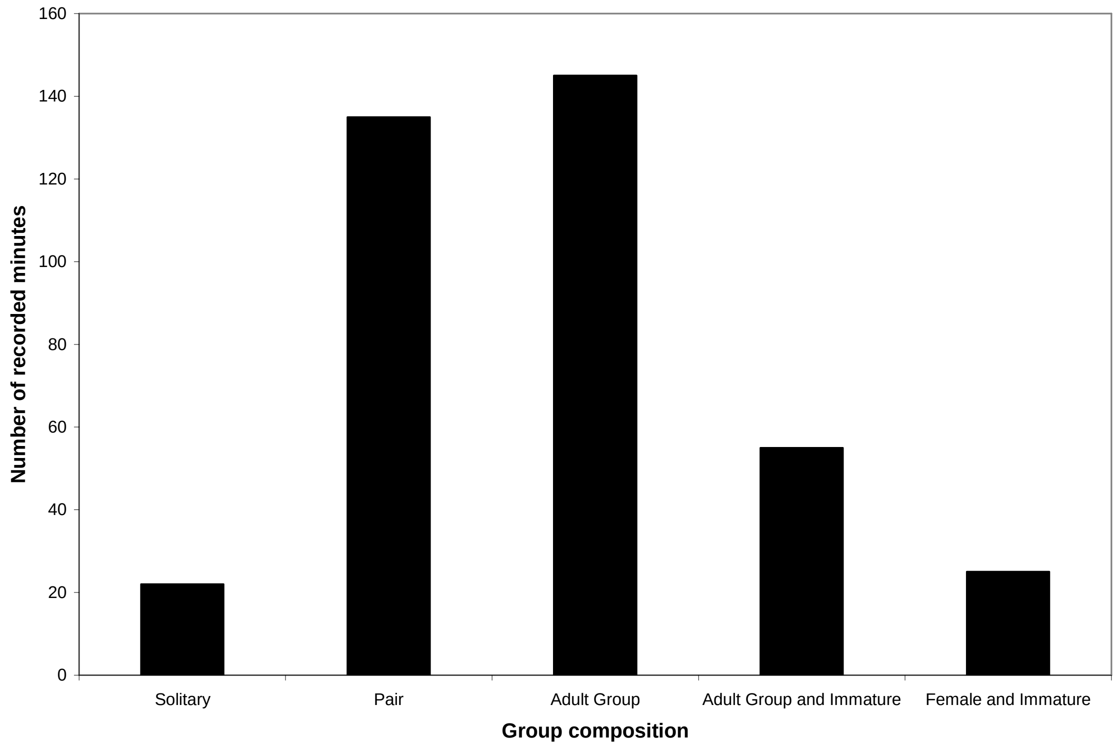

Figure 8. Distribution of bottlenose dolphin group composition for 380 recorded minutes.

The Kruskal-Wallis test was employed to analyze the differences in whistle production rates among the different group compositions. Results of the Kruskal-Wallis test ($p = 0.0024$) are shown in Table 2. The whistle production rates of adults in the presence of an immature calf showed a significant difference to those of any other group ($p \leq 0.05$), while all other groups did not show a significant difference in the production of whistles ($p \geq 0.05$). Since the Kruskal-Wallis test analyzes rank, median values of whistle production rates serve as a representative statistical value. The median value of whistle production rate was much higher for the adult group and immature (median = 0.5) than the median of all the other groups (median = 0 for all other groups). These results suggest that whistle rates of a group of adult bottlenose dolphins increases in the presence of immature dolphins.

Characterization of Whistles

One hundred seventy six whistles with acceptable signal-to-noise ratio were analyzed for whistle characteristics from the three hundred eighty two whistles collected. Data on the eight parameters measured are summarized in Table 3. For comparison, acoustic measurements of whistles from previous published studies on bottlenose dolphin populations are summarized in Table 4. All whistle parameters calculated in this study were found to be similar to those in previous studies (Table 4).

Table 2. Results of the Kruskal-Wallis test analyzing differences in whistle production rates among different group compositions (p = 0.0024).

	Solitary	Pair	Adult Group	Adult Group and Immature (n=1)	Female and Immature (n=1)
Solitary		0.6263	0.1895	0.000129	0.6263
Pair	6.263		0.4249	0.002341	0.9892
Adult Group	1.895	4.249		0.02564	0.4249
Adult Group and Immature (n=1)	0.001294	0.02341	0.2564		0.002341
Female and Immature (n=1)	6.263	9.892	4.249	0.02341	

Table 3. Summary of main characteristics of bottlenose dolphin whistles recorded from Golfo Aranci, Sardinia, Italy (*n* = 176).

Measurements	Mean	Standard Deviation	Minimum	Maximum
Duration (s)	0.785	0.605	0.036	4.354
Initial frequency (Hz)	9003.845	2300.047	5637.500	17875.000
Quarter Frequency (Hz)	10055.043	2458.160	5775.000	19662.500
Half Frequency (Hz)	10902.791	2679.612	5912.500	19525.000
2nd Quarter Frequency (Hz)	11704.029	2940.392	5775.000	19112.500
Final Frequency (Hz)	12031.262	4131.467	0.016	20212.500
Minimum Frequency (Hz)	8016.719	2010.246	3575.000	17737.500
Maximum Frequency (Hz)	14193.205	2623.808	9260.175	20212.500

Table 4. Whistle characteristics from different bottlenose dolphin populations (as adapted from dos Santos et al., 2005).

Location	Duration (s)	Frequency Range (kHz)	Minimum Frequency (kHz)	Maximum Frequency (kHz)	Reference
Golfo Aranci, Sardinia	0.79	6.18	8.02	14.19	*Present Study*
Sado Estuary, Portugal	0.86	9.60	5.40	15.00	dos Santos et al., 2005
Isla del Coco, Costa Rica	0.38 0.66	4.90 5.46	7.51 8.51	12.41 13.96	Acevedo-Gutiérrez and Stienessen, 2004
Moreton Bay, Australia	0.34	6.44	4.32	10.76	Ong, 1996 (*T. aduncus*)
Galveston, TX	0.75	5.97	5.98	11.95	Wang et al., 1995
Corpus Christi Bay, TX	0.69	5.55	5.88	11.43	Wang et al., 1995
South Padre Island, TX	0.60	4.96	5.37	10.33	Wang et al., 1995
Golfo San José, Argentina	1.14	7.74	5.91	13.65	Wang et al., 1995
Gulf of California, Mexico	0.66	6.77	6.91	13.68	Wang et al., 1995
Shark Bay, Australia	0.68	7.00	3.57	10.57	Wang et al., 1995
Taiji, Japan	0.62	4.25	7.37	11.62	Wang et al., 1995
Captives, mostly from Florida	0.95	10.66	4.26	14.98	Caldwell et al., 1990
Western North Atlantic	1.30	8.91	7.33	16.24	Steiner, 1981

Discussion

The purpose of this study was to contribute to the ongoing effort to understand the acoustic emissions of the bottlenose dolphin population in Golfo Aranci by focusing on whistle characteristics and production rates. Our study set out to answer two questions regarding whistle production rates among bottlenose dolphin groups. First, are whistle production rates affected by the number of dolphins in a group, and second, are whistle production rates affected by the presence of a mother and calf pair?

Bottlenose dolphins at Golfo Aranci increased their whistle production rate during feeding events as more dolphins joined the group ($r = 0.457$, $p \leq 0.001$). The highly significant positive correlation between whistles per minute and the dolphin group size demonstrated the fact that whistle rates increased when dolphin groups consisted of a larger number of individuals as compared to groups of smaller numbers. These findings are consistent with previous data on whistle production rates in wild and captive bottlenose dolphins. Acevedo-Gutierrez and Stienssen (2004) found bottlenose dolphins in Costa Rica increased their whistle production during feeding events. Likewise, Jones and Sayigh (2002) found a strong positive correlation between group size and whistle production.

There may be reasons as to why the dolphins at Golfo Aranci increased their whistle production rates as the number of dolphins during feeding events increased. Dolphins utilize whistles to communicate with one another and are known to employ the characteristics of individual whistles to convey information (Janik and Slater, 1998). As previous studies have indicated, whistle production rates may also serve a similar function (Acevedo-Gutierrez and Stienssen, 2004). In addition to the increased whistle rates during feeding events, Acevedo-Gutierrez and Stienssen (2004) also found that new dolphins arrived at the onset of feeding events, suggesting that increased whistle production during feeding events may serve as cues to other dolphins in the area of a feeding event. They hypothesized that these dolphins were attempting to recruit more dolphins in order to out compete the sharks and reduce competition. Additionally, whistle production and activity have been shown to be related (Cook et al., 2004; Jones and Sayigh, 2002). For example, whistle rates tend to be higher for social and feeding events or when the dolphins are in an excited state. Although there are no sharks in Golfo Aranci, the increase in whistle production as the group size increased found in this study might be explained by the dolphins' desire to recruit more individuals to enhance feeding strategy. Likewise, the increase in whistle rate may be due to the excited state of social interaction with other group members. Future studies should look into these possibilities.

Whistle rates were also found to increase in groups of adult bottlenose dolphins when in the presence of immature dolphins (Table 2). In the wild and in captivity, calves form strong bonds with their mothers keeping a close affiliation with her for years, sometimes well into adulthood (Defran and Pryor, 1990). Mother-infant pairs are known to frequently separate and reunite, yet very young calves tend to spend more time in close proximity to their mothers. Mother-infant pairs are often seen traveling alone, although they will associate with other group members on occasion for purposes such as feeding (Smolker et al., 2003). Fortunately due to the presence of the fish farm, we were able to obtain recording samples of both the mother-infant pair feeding alone and with a group of adults.

The infant or immature dolphin in this study was estimated by the BDRI staff to be around two to three weeks old and spent much of its time at its mother's side during our two observational sightings of the pair. According to Smolker et al. (2003) infants will whistle commonly when separated from their mother, but rarely while they are together. Since bottlenose dolphins are capable of whistling and other sound production from birth, there are two possible reasons for the increased whistle rates in the group of adults in the presence of the immature. There may be an increase in whistle production rates due to communication between the adult and immature dolphins, or the adults may be increasing their whistle rates in response to the presence of the immature dolphin. Unfortunately the determination of which possibility is true could not be further tested as the infant died only after two recordings.[1]

All whistle parameters calculated in this study were found to be similar to those in previous studies (Table 3 and 4). Only 176 of the 382 whistles were available for whistle characteristic determination due to high noise pollution in many of the recorded minutes. All observations and recordings were collected at the fish farm where noise produced from the fish farm boats provided much noise pollution during working hours.

Whistles recorded at Golfo Aranci were relatively long, only four of the thirteen other studies reported whistles with longer average duration. According to Caldwell et al. (1990), whistles of longer duration seem to be easier to locate than those of shorter duration. Additionally, the maximum and minimum frequencies in our whistle samples were relatively higher than those of the other populations, with only two populations having a higher average maximum frequency and only one population having a higher

[1] The newborn in this study died after it was caught in a fishing net a few weeks after our last recording of him.

minimum frequency. Since the noise pollution in and around the fish farm is very high in Golfo Aranci, longer whistles of generally higher frequencies may make it easier for other dolphins to hear. As this aim of our study was secondary, future studies need to be undertaken to further understand the reasons for these results.

Summary and Conclusion

Bottlenose dolphins are acoustically oriented animals that depend on sound production for survival. As such, vocal communication of the bottlenose dolphin has been the focus of much research done on these animals, including this study. By focusing on whistle production rates and characteristics, the data presented in this study contribute towards the ongoing effort of researchers to understand the importance and function of bottlenose dolphin whistles in wild populations. Whistle production rates of bottlenose dolphins in Golfo Aranci were analyzed and found to be influenced by both group composition and group size. A positive relationship was found between whistle rates and group size, suggesting that individual dolphins tend to whistle more in groups of larger numbers. Whistle rates of dolphin groups were found to increase also in the presence of an immature dolphin as compared to its absence. Whistle characteristics measured in this study revealed whistles to be of general longer duration and higher frequency than those reported in previous studies.

Dolphins utilize whistles to communicate with one another and are known to employ the characteristics of individual whistles to convey information. Similarly, whistle production rates have been thought to serve a similar purpose. As suggested in both the present and previous studies, whistle production rates do increase with larger group sizes and in the presence of immatures, but the function of these increases in communication have not been explicitly determined. Further studies should focus on the communicative function of whistle production rates to determine whether or not these production rates serve to convey specific information, such as recruiting other dolphins to feeding events.

Despite the fervent efforts of researchers for four decades, we still have a limited understanding of the function and meanings of dolphin whistles, specifically across changes in behavior, group size, and group composition. Clearly, the function and production of whistles require further research, especially in wild populations. By understanding the relationship between dolphin vocalizations and behavior, vocal activity may serve as an outlet to better understand bottlenose dolphin behavior and enable us to make more informed decisions regarding both conservation efforts and welfare in captivity.

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